10Gbps Parametric Short-Wave Infrared Transmitter

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Abstract: We demonstrate the first 10Gb/s parametric transmitter in short-wave Infrared band. The device operates by converting 1278nm signal over 85THz to generate channel at 2002nm using highly-nonlinear-fiber and was characterized by error-free performance.

OCIS codes: (190.4380) Nonlinear optics, four-wave mixing; (060.2390) Fiber optics, infrared.

1. Introduction

The short-wave infrared (SWIR) region has important role in applications such as free-space communications, biological and chemical sensing, spectroscopy, as well as light detection and ranging (LIDAR) [1]. The sensitivity and efficiency of all applications would greatly benefit by construction of coherent SWIR source capable of encoding both amplitude and phase to an optical carrier. While critical importance of coherent modulation in free-space communications is well understood, it is also essential for improving the sensitivity in spectroscopy and sensing applications [2]. However, the conventional optical components that are designed for near-infrared (NIR) cannot operate in SWIR band for both practical and fundamental reasons. The use of four-wave mixing (FWM) in highly nonlinear fiber (HNLF) has previously been identified as an effective way to map NIR to SWIR band [3,4]. Furthermore, NIR-to-SWIR conversion has been demonstrated in micro-coiled HNLF thus allowing for ultra-compact portable transmitter platform [5]. Specifically, the nature of the FWM process allows for continuous tunability across wide frequency range, preserves the source linewidth and supports the translation of advanced modulation formats.

This submission describes, for the first time, to the best of our knowledge, translation of 10Gb/s non return-to-zero (NRZ) signal over 85THz from the O-band (1278nm) to the SWIR band (2μm). The SWIR transmitter was constructed using HNLF parametric mixer and standard telecom band components, eliminating the need for specialized components such as SWIR high-rate optical modulators.

2. Experimental setup

The experimental setup for the 10Gb/s modulated data streams' parametric conversion to 2μm in HNLF is shown in Figure 1.

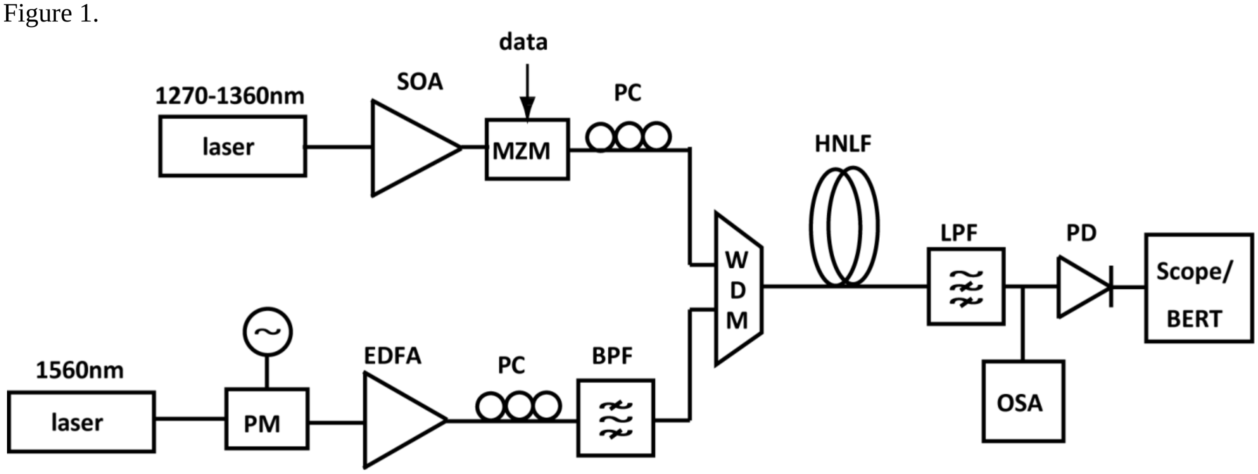

Figure 1. Experimental setup; EDFA: erbium-doped fiber amplifier, SOA: semiconductor optical amplifier. MZM: mach-zehnder intensity modulator, WDM: Wavelength Division Multiplexer, PM: Phase modulator, PD: photodetector, ISO: isolator, HNLF: highly nonlinear fiber, BPF: band pass filter, LPF: long-pass filter, OSA: optical spectrum analyzer, PC: polarization controller.

The signal seed, tunable between 1270-1360nm, was amplified using an O-band semiconductor optical amplifier (SOA). In addition, the SOA was placed immediately after the laser to preempt the SOA inherent relaxation oscillations. A polarization controller preceding the SOA ensured the proper input signal polarization. Subsequently, the seed was amplitude modulated (MZM) using 10Gb/s non-return-to-zero pseudo-random bit sequence (PRBS). The continuous-wave (CW) pump was appropriately positioned at 1560.1nm close to the zero dispersion wavelength of the HNLF fiber. The pump was first spectrally broadened using a phase modulator (PM) driven by the RF noise source with 0.4GHz bandwidth to suppress stimulated Brillouin scattering in the HNLF, and then amplified using erbium-doped amplifiers (EDFAs). Carrier suppression was monitored on a high resolution SWIR optical spectrum analyzer (OSA). The excess amplified spontaneous emission after last stage EDFA was rejected using a tunable double-cavity band-pass filter with 2nm bandwidth. After filtering, the pump was combined with the signal using a wavelength-division multiplexer (WDM) and launched into ~100m of HNLF to generate an idler at ~2µm. The HNLF was characterized by a zero dispersion wavelength of 1560.5nm, dispersion slope S of 0.026ps/(km nm^2) and measured fourth-order dispersion coefficient β_4 of $2.3{\cdot}10^{-56}$ s^4/m. The pump power at the input to the HNLF was 2.5W, while the input signal power was 9.7dBm. After filtering out the seed and the pump using a long-pass filter (LPF) at 1640nm, the isolated 2.002µm idler was directed to an OSA and a 10GHz InGaAs PIN-detector (PD) for its integrity analysis. The OSA was set to a resolution bandwidth of 0.2nm with a sensitivity of -70dBm. The signal from the PD was amplified using a limiting amplifier and the waveform was sampled using a digital oscilloscope and received by the analyzer section of the bit-error-ratio tester (BERT) for rigorous idler performance quantification.

3. Results

The spectrum of the converted 2002nm idler is shown in Figures 2(a) and 2(b). Due to unavailability of filtering components at 2µm, standard telecom band long-pass filter was used to isolate the 2002nm idler in this experiment. The spectrum at the output of the HNLF before the LPF was obtained using a 30dB of inline attenuator and reflects its spectral response (Figure 2(a)). The long-pass filter introduced a significant loss of 7dB at the idler wavelength. Consequently, actual generated idler power straight out of the HNLF was -0.5dBm (0.89mW) for the -7.5dBm power level measured after the LPF. The FWM conversion efficiency was, therefore, -10.2dB over the 700 nm range, with a noise floor around the 2µm idler 40dB lower than the peak idler power. The transmitter performance was further hampered by the LPF transfer characteristic which passed a significant amount of the wide band ASE noise around the pump (with a total power of ~-18dBm) originating from the Raman gain in this spectral region, that was unimpededly present at the detector, thus significantly deteriorating the performance.

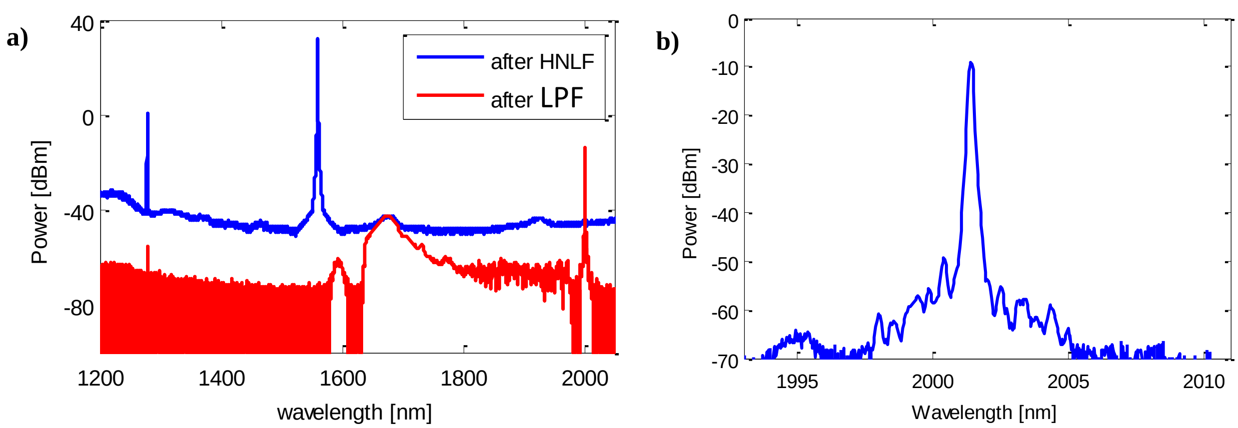

Figure 2. a) Conversion spectrum after HNLF, reflecting the response of 30dB of inline attenuator at high powers compared with spectrum after the LPF with pump and seed filtered out. The 30dB attenuator has a flat attenuation from 1400nm to 1700nm but skews the spectrum elsewhere and hence the power around 1300nm is attenuated more than at 1560nm. The spectrum is limited by the sensitivity of the OSA. b) converted idler at 2002nm

A 10^{31}-1 long PRBS pattern was used to capture the transmitter performance (i.e. the eye diagrams) and to measure the bit-error-ratio (BER). Both responses at 1278nm seed and 2.002µm idler were measured using the same 10GHz detector. Two modulation speeds, 2.5Gb/s and 10Gb/s were used in the experiments. The eye diagrams for 2.5Gb/s modulation are shown in Figure 3(a) and 3(b). The BER curves show error-free performance at 2002nm with penalty of 0.25dB compared with back-to-back signal at 1278nm. The penalty is partially imposed by inefficient rejection of the spectral noise beyond the 1640nm due to non-standard components that were used to filter out the converted signal at 2002nm (Figure 2(a)).

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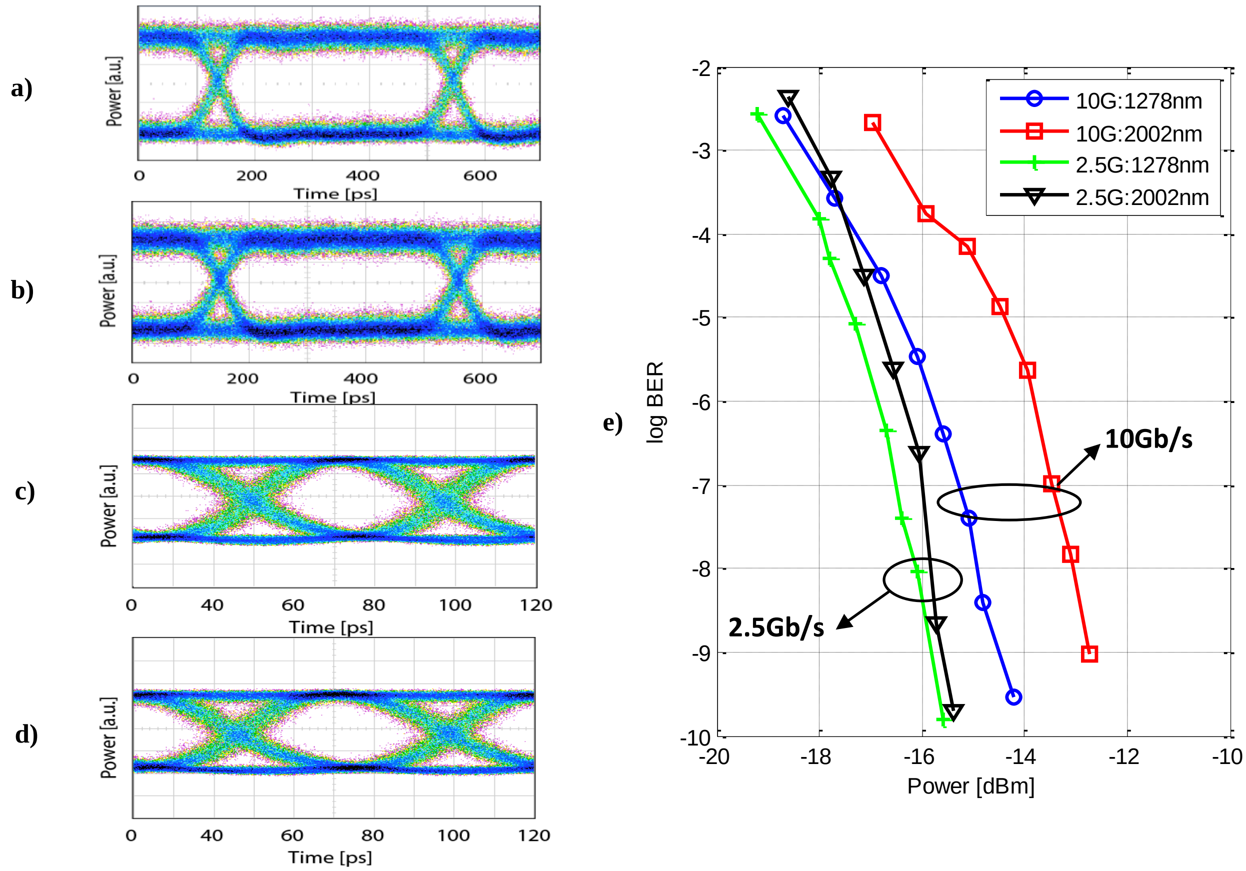

Figure 3. Eye diagrams for 2.5Gbps signal a) 1277.8nm, b) 2.002µm, eye diagrams for 10Gb/s signal: c)1278nm seed and d) 2.002µm idler and e) BER curves for seed and idler for 2.5Gb/s and 10Gb/s

Figures 3(c) and 3(d) show eye diagrams for 10Gb/s modulation. The slow rise and fall time were typical for the 10GHz band-limited detector. The characterized penalty for the 10 Gb/s reception was 1.9dB (i.e., 1.65dB higher than that in the 2.5Gb/s case). This elevated penalty is attributed to the higher ASE noise in pump vicinity, as compared to the case of 2.5Gb/s which was a consequence of the higher pump power in the latter case.

4. Conclusion

The operation of first parametric 10Gbps SWIR transmitter is reported. The SWIR channel generation was accomplished by translation of 2.5Gb/s and 10Gb/s NRZ modulated signal over 85THz from the fiber-optic communication window (O-band) to the SWIR (2µm) band. The first OC-192 SWIR channel was characterized by error-free performance for the first time. At 2002nm, -0.5dBm (0.890mW) of optical power was generated by means of a parametric conversion in a highly non-linear fiber. Measured penalties at 10Gb/s and 2.5Gb/s data streams, for the SWIR transmitter were to 1.9dB and 0.25dB , respectively, as compared to the back-to-back signal at 1278nm. The experimental demonstration validates the parametric SWIR transmitter concept for free-space communications, sensing and LIDAR applications, and is compatible with cm-scale footprint inherent to HNLF micro-coils.

5. Acknowledgments

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6. References

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